

Short-Term Satiety and Glycemic Response After Consumption of Whole Grains with Various Amounts of β -Glucan

HYUNSOOK KIM,¹ KAY M. BEHALL,¹ BRYAN VINYARD,² AND JOAN M. CONWAY^{1,3}

ABSTRACT

The effects of a meal with and without soluble dietary fiber in the form of β -glucan on short-term satiety and glucose response were investigated in 19 overweight subjects. Subjects consumed four isocaloric test meals consisting of a glucose solution or wheat (0 g of β -glucan), a wheat-barley mixture (1 g of β -glucan), or barley (2 g of β -glucan) served as cooked cereal with low-fat strawberry yogurt. Subjects used visual analog scales (VAS) to rate their hunger, fullness, satisfaction, thirst, nausea, and drowsiness at timed intervals before and after consumption of each test meal. Blood glucose was measured periodically, and energy intake was recorded 2 hr after consumption of each test meal. In women peak glucose responses and area under the curve were significantly lower after consumption of 2 g of β -glucan compared with consumption of 0 or 1 g of β -glucan. VAS ratings did not significantly differ among cereals. In men no effect of β -glucan on glucose response was observed, and β -glucan had only a marginal effect on VAS ratings. Energy intake was not affected by β -glucan level in either women or men. The findings indicate that acute reduction of glycemic response in overweight women requires the consumption of at least 2 g of β -glucan per meal, and greater amounts of β -glucan per meal may be required to achieve substantial satiety effects in overweight women and men.

Consumption of a diet high in soluble fiber has been suggested as a strategy to reduce the risk factors for development of obesity through the regulation of satiety and energy intake. In addition, such a diet is purported to reduce cholesterol and improve postprandial insulin and glucose response (24). The suggested mechanisms include malabsorption, increased gastric distention, decreased rate of gastric emptying, regulation of satiety hormones, and reduced glycemic index (16,19,24).

Consumption of soluble fibers such as guar gum, methylcellulose, and pectin reduced the rating of perceived hunger and energy intake and improved weight maintenance under fixed energy intake conditions in several studies (15–17,22,23,29). However, few studies have considered the

role of the soluble fiber β -glucan in weight management. Furthermore, studies using β -glucan from barley or oats showed inconsistent results, with both positive (4,25) and negative (14,26) effects on satiety, energy intake, and weight loss. A recent study using cultured adipocytes and mice found that leptin was produced in proportion to short-chain fatty acids (SFAs) (33), suggesting a possible role for SFAs, which are fermented products of soluble fiber, in the regulation of satiety and energy intake.

To clarify the potential role of β -glucan in the regulation of short-term satiety in over-

weight women and men, we tested whether consumption of whole-grain cereals with various β -glucan contents affects acute satiety ratings, energy intake, and postprandial glucose response.

MATERIALS AND METHODS

Subjects

Ten women and 10 men were screened, and 10 women and nine men completed the study. One man did not complete the study because of noncompliance. A medical history questionnaire was used to exclude subjects with a chronic disease, such as gout, diabetes, or other metabolic or malabsorption disease, and those using medications affecting glucose metabolism. Inclusion criteria included age > 40 years, body mass index (kg/m^2) > 25, fasting blood glucose < 6.99 mmol/L (126 mg/dL), waist circumference > 100 cm in men and > 88 cm in women, and blood pressure < 140/90 mm Hg. Body fat (percent) was measured by bioelectrical impedance (TANITA body composition analyzer, model TBF-300A, Biodynamics, Seattle). All subjects were nonsmokers, nonathletes, not pregnant or lactating, free from food allergies, not dieting, and weight stable for the past year. During the screening, subjects completed several questionnaires, including the Eating Inventory (27) for assessing dietary restraint, disinhibition,

Table I. Subject characteristics^a

Characteristic	Men (<i>n</i> = 9)	Women (<i>n</i> = 10) ^b
Age (years)	57.2 ± 3.3	50.9 ± 2.7
Height (cm)	178.4 ± 1.9	163.5 ± 1.9*
Weight (kg)	92.8 ± 2.8	85.3 ± 4.4
Body mass index (kg/m^2)	29.2 ± 0.7	31.8 ± 1.2*
Body fat (%)	29.1 ± 1.4	44 ± 1.2*
Waist circumference (cm)	104 ± 2.4	102 ± 3.3
Waist/hip ratio	0.96 ± 0.01	0.88 ± 0.01*
Fasting blood glucose (mmol/L)	5.64 ± 0.18	5.67 ± 0.17
Dietary restraint score ^c	8.7 ± 1.3	9.7 ± 0.9
Disinhibition score ^c	4.0 ± 0.8	7.8 ± 1.3*
Hunger score ^c	3.1 ± 0.9	5.1 ± 0.9

^a All data expressed as mean ± SEM.

^b * indicates values are significantly different ($P < 0.05$) between men and women.

^c Eating Inventory scores (27).

¹ USDA, ARS, BHNRC, Diet and Human Performance Laboratory, Beltsville, MD.

² USDA, ARS, BARC, Biometrical Consulting Service, Beltsville, MD.

³ Corresponding author. USDA, ARS, BHNRC, Diet and Human Performance Lab, Bldg. 307B, Rm. 213, Beltsville, MD 20705. Phone: 301/504-8977; E-mail: ConwayJ@ba.ars.usda.gov.

and hunger; the Godin Leisure Time Exercise Questionnaire (11) for physical activity; and the Marlowe-Crowne Social Desirability Scale (8) for personal reaction inventory. Scores on these questionnaires were not used as selection criteria. Subject characteristics are shown in Table I. The study was approved by the Institutional Review Board of the Medstar Research Institute (Hyattsville, MD).

Study Design

The study consisted of two experimental days: day 1, controlled feeding; and day 2, glucose or whole-grain cereal meal tolerance tests and measurements of satiety. On day 1, subjects followed the suggested menu, which contained 15% protein, 50% carbohydrate, and 35% fat for breakfast and lunch; a standardized dinner and snack were provided. On day 2, subjects arrived at the Beltsville Human Nutrition Research Center in the morning after an 11-hr fast, completed baseline testing, and then ate their breakfast (test meal) within 10 min. Subjects rated their hunger, fullness, satisfaction, thirst, nausea, and drowsiness on 100-mm

visual analog scales (VAS) (7) at 15 min before and 0, 15, 30, 60, 120, and 150 min after consuming a test meal. Subjects ate a standardized lunch 2 hr after breakfast. For lunch, they were instructed to eat as much as they desired until they felt comfortably full. This lunch meal contained 2,000 kcal and consisted of baked macaroni and cheese (Stouffers, Nestle USA, Inc., Solon, OH) and 1 L of water. The energy intake during lunch was determined by subtracting the amount of food not eaten from the total amount of food offered. VAS scores and energy intake were used as estimates of satiety. For the tolerance tests, blood glucose levels were determined at the same times as the VAS measurements, using an over-the-counter glucometer (Therasense, Alameda, CA). Perception of the test meals was measured using VAS.

Subjects were not allowed to talk and were asked to read books or magazines that did not contain any articles related to food or weight loss. They were also asked to remain in their own cubicles during the study session. All subjects were told that the purpose of the study was to examine the per-

ception or experience of eating foods containing the naturally occurring soluble fiber β -glucan from barley. A debriefing questionnaire was conducted at the conclusion of the experiment. Most subjects thought the purpose of the study was to examine their glucose response after eating.

Test Meals

The breakfast test meals, containing 75 g of glucose solution or whole-grain cereal, were given to subjects in a Latin-square design. Cereal test meals contained 50 g of wheat (0.43 g of β -glucan), 25 g of wheat and 25 g of barley (1.23 g of β -glucan), or 50 g of barley (2.03 g of β -glucan) and were served as hot cereal with 106 g of commercially prepared low-fat strawberry yogurt. Energy (300 kcal), macronutrient, and water intake (235 g) were controlled across the three cereal test meals (Table II). The calculated total dietary fiber content for all cereal meals was 7.4 g. Wheat was obtained locally, and barley was obtained from Briess Malt & Ingredients Co. (Chilton, WI). Wheat and barley β -glucan contents were determined by the mixed-linkage β -glucan method (21), using a streamlined enzymatic method (Megazyme International Ireland, Ltd., Wicklow, Ireland).

Table II. Content and composition of test meals

Component (g)	Test Meal			
	Glucose	0 g of β -Glucan	1 g of β -Glucan	2 g of β -Glucan
Wheat	0	50	25	0
Barley	0	0	25	50
Yogurt	0	106	106	106
Protein	0	9.2	9.1	9.1
Carbohydrate	75	58.3	59.1	59.8
Fat	0	3.3	3.4	3.4

VAS Measurements

Adapted from Cardello and coworkers (7), VAS was a vertical line (100 mm) anchored with phrases such as "greatest imaginable hunger" at positions corresponding to their geometric mean magnitude estimates. Subjects used VAS to rate their fullness, satisfaction, hunger, "how much can you eat?" (HC), drowsiness, nausea, and thirst and the pleasantness of the meals. The distance from the bottom end of the scale to the mark made by the subject was measured with a digital caliper (Cen-Tech, Tualatin, OR). Each VAS measurement was taken six times.

Statistical Analysis

Repeated-measures analysis of variance was used to determine statistically significant differences (PROC MIXED, version 9.1.3., SAS Institute, Cary, NC). Differences between groups were determined by least significant difference at $P < 0.05$. Linear orthogonal polynomial contrasts were used to test the significance of the amount of β -glucan (0, 1, and 2 g) consumed. All data are expressed as mean plus/minus standard error of the mean.

RESULTS AND DISCUSSION

Effects of β -Glucan on Glycemic Response

Studies have shown that consumption of β -glucan from oats or barley improves glycemic response in overweight subjects or subjects with type II diabetes (3,5,9,12,13, 25,28,34), possibly through a delay in carbohydrate absorption rather than through the effects of fermentation products (2). Re-

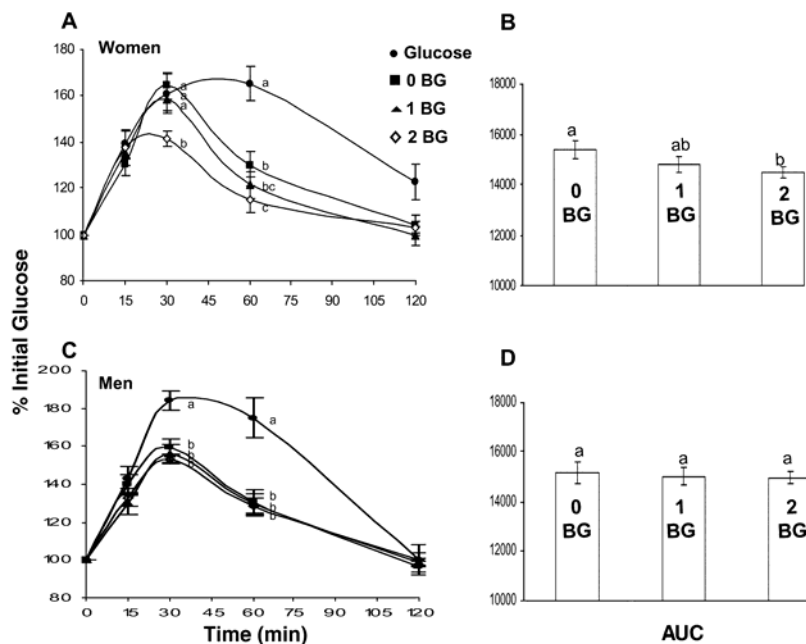


Fig. 1. Glucose response after consumption of test meals containing glucose or 0, 1, or 2 g of β -glucan in 10 overweight women and nine overweight men. **A and B**, Glucose response and area under the curve (AUC) for women; **C and D**, glucose response and AUC for men. Data are expressed as mean \pm SEM. Different letters indicate significant difference at $P < 0.05$. Glucose = 75 g of glucose solution as glucola; 0 BG = 0 g of β -glucan (wheat); 1 BG = 1 g of β -glucan (50% wheat and 50% barley); and 2 BG = 2 g of β -glucan (barley). The three cereal meals were served hot with low-fat strawberry yogurt.

search has found that the beneficial effects of β -glucan from oats on glycemic response are dose-dependent in an inverse linear relationship (12,28,32). Studies using β -glucan from barley also have revealed a more potent effect of high β -glucan consumption on glycemic response (3,18,31,34).

Our data are consistent with earlier studies. In women the peak glucose response at 30 min was significantly lower after consumption of 2 g of β -glucan than after consumption of 0 or 1 g of β -glucan (Fig. 1A). A significant reduction was also found 60 min after consumption of 2 g of β -glucan compared with consumption of 0 g of β -glucan. Orthogonal polynomial contrasts showed a linear decline in glucose response to β -glucan (0, 1, and 2 g) at 30 min ($P = 0.003$) and 60 min ($P = 0.049$). The area under the curve (AUC) was significantly lower after consumption of 2 g of β -glucan than after consumption of 0 g of β -glucan (Fig. 1B) and decreased linearly ($P = 0.01$) as the amount of β -glucan increased from 0 to 2 g. In men no significant differences were observed in peak glucose response or AUC (Fig. 1C and D).

These findings suggest that in overweight women, acute reduction of glycemic response requires consumption of at least 2 g of β -glucan per meal. In overweight men consumption of greater amounts of β -glucan per meal may be required for a substantial effect on postprandial glucose response; the mechanism is not clear, however. Given that body weight was not significantly different between women and men, consumption of an equivalent amount of β -glucan by both genders may not be a limiting factor in our study design.

Effects of β -Glucan on Short-Term Satiety

The effects of β -glucan on satiety were marginal in both overweight women and men. In both women and men, the ratings for fullness and satisfaction rapidly rose and remained high until about 60 min after consumption of a cereal test meal and then decreased to almost fasting levels by 120 min (Fig. 2). Fullness and satisfaction ratings were not affected by β -glucan in either women or men (Fig. 2). In men a separate within cereal statistical comparison showed that the satisfaction rating was significantly greater (15.4%) 15 min after consumption of 2 g of β -glucan than after consumption of 1 g of β -glucan (data not shown). Fullness and satisfaction ratings for 15–60 min after consumption of glucose alone were significantly lower than those after consumption of a cereal test meal in women; the effect was weaker (ratings for 15–30 min) in men (Fig. 2).

Ratings for hunger and HC rapidly decreased and then gradually rose to approximately fasting levels by 120 min after consumption of a cereal test meal in both women and men (Fig. 3). In women consumption of 2 g of β -glucan decreased the

hunger rating at 30 min compared with 0 and 1 g of β -glucan by 44 and 36%, respectively, but the differences were not statistically significant (Fig. 3A). The hunger rating at 60 min for consumption of 2 g of β -glucan increased rapidly, whereas it remained low for 1 g of β -glucan (Fig. 3A); these values were significantly different. In men there was no significant difference in hunger rating among the cereal test meals (Fig. 3B). β -Glucan did not significantly affect the overall rating

for HC in women or men (Fig. 3C and D). Orthogonal polynomial contrast analysis showed there was no linear response to β -glucan (0, 1, and 2 g) in the ratings for fullness, satisfaction, hunger, and HC in either women or men.

No effect of β -glucan on energy intake at 2 hr after consumption of test meals was seen in either women or men (Fig. 4). Water intake was not affected by β -glucan consumption in women or men (data not

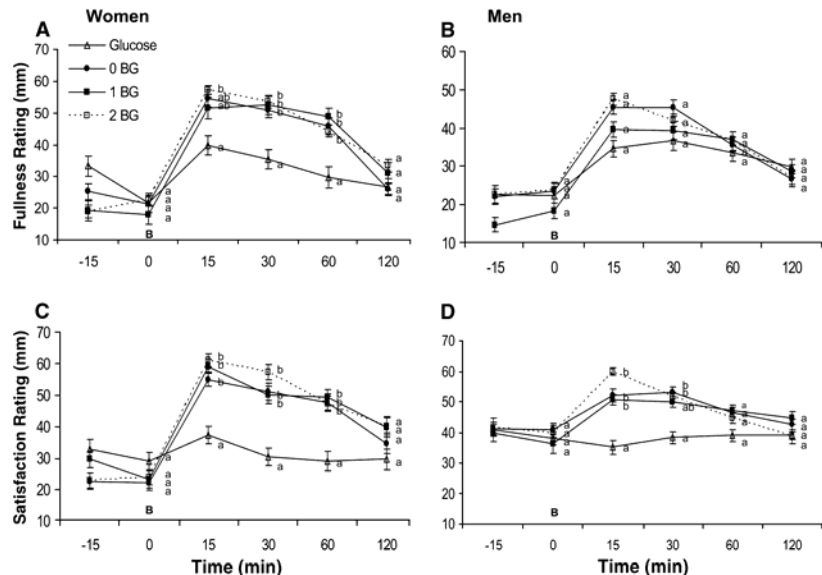


Fig. 2. Fullness (A and B) and satisfaction (C and D) ratings after consumption of test meals containing glucose or 0, 1, or 2 g of β -glucan for 10 overweight women (A and C) and nine overweight men (B and D). Data are expressed as mean \pm SEM. Different letters indicate significant difference at $P < 0.05$. Glucose = 75 g of glucose solution as glucoola; 0 BG = 0 g of β -glucan (wheat); 1 BG = 1 g of β -glucan (50% wheat and 50% barley); and 2 BG = 2 g of β -glucan (barley). The three cereal meals were served hot with low-fat strawberry yogurt.

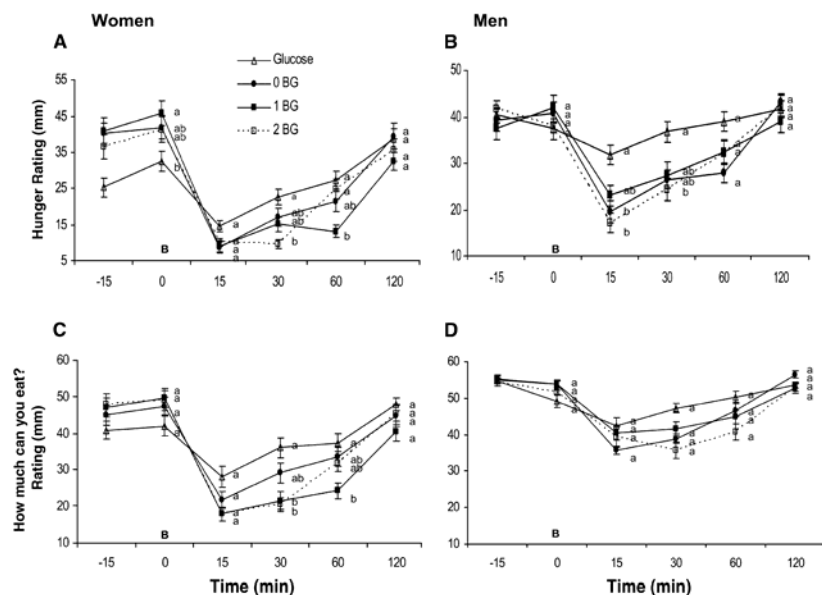


Fig. 3. Hunger (A and B) and “how much can you eat?” (C and D) ratings after consumption of test meals containing glucose or 0, 1, or 2 g of β -glucan for 10 overweight women (A and C) and nine overweight men (B and D). Data are expressed as mean \pm SEM. Different letters indicate significant difference at $P < 0.05$. Glucose = 75 g of glucose solution as glucoola; 0 BG = 0 g of β -glucan (wheat); 1 BG = 1 g of β -glucan (50% wheat and 50% barley); and 2 BG = 2 g of β -glucan (barley). The three cereal meals were served hot with low-fat strawberry yogurt.

shown). These observations indicate that consumption of 2 g of β -glucan per meal is unlikely to affect short-term control of satiety and energy intake in either overweight women or men.

Pleasantness ratings for the cereal test meals were not significantly different for women and men (data not shown). The pleasantness rating for the glucose solution by both women and men was significantly lower than those for the cereal test meals (data not shown). There were no significant differences in ratings for drowsiness, nausea, and thirst in response to consumption of 0, 1,

or 2 g of β -glucan in either women or men, except that the nausea rating was significantly higher at 120 min after consumption of 1 g of β -glucan compared with 0 g of β -glucan (from 50 ± 13 to 29 ± 9 mm) in women (data not shown).

Because the test meals were matched for energy content (300 kcal) but not for macronutrient content and physical form (liquid versus solid) (Table II), comparison of the results for glucose and cereal test meals had some limitations. The timing of the consumption of test meals (time lag between preload and lunch) may be more important than

physical form for inducing satiety effects. This has been suggested by some studies that show a positive effect of solids on satiety at intervals of 2–4 hr (10,30) and others showing no effect of physical form on satiety rating and energy intake at 2 hr after preloading (1,20). In our study, satiety ratings were not higher for solid cereals than for liquid glucose 2 hr after test meals were consumed. However, at the early stage (15–60 min) after consuming a test meal, the overall satiety rating for fullness and satisfaction with glucose was significantly lower than for the cereal test meals. A different response by gender was not anticipated, although an earlier study (6) reported a weak effect of fiber on energy intake for men compared with women. Additional research is required to validate the effects of β -glucan on satiety by increasing sample sizes of both women and men.

CONCLUSIONS

In the current study, consumption of barley containing the soluble fiber β -glucan lowered glycemic response in a dose-dependent manner in overweight women but not in overweight men. Consumption of at least 2 g of β -glucan per meal could be part of a suggested dietary plan to reduce risk factors for development of type II diabetes in overweight women. The lack of ef-

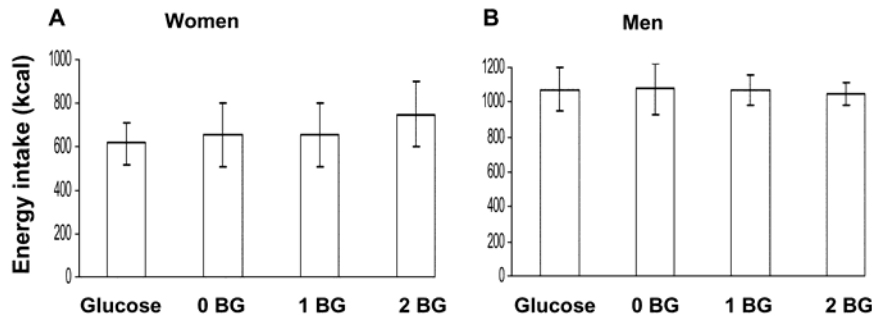


Fig. 4. Energy intake at 2 hr after consumption of test meals containing glucose or 0, 1, or 2 g of β -glucan for 10 overweight women (**A**) and nine overweight men (**B**). Data are expressed as mean \pm SEM. Energy intake was determined as a standardized lunch provided 2 hr after test meals were consumed. Glucose = 75 g of glucose solution as glucola; 0 BG = 0 g of β -glucan (wheat); 1 BG = 1 g of β -glucan (50% wheat and 50% barley); and 2 BG = 2 g of β -glucan (barley). The three cereal meals were served hot with low-fat strawberry yogurt.

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fects of β -glucan on satiety and energy intake suggests that larger doses of β -glucan (>2 g/meal) may be required to substantially affect short-term satiety and, therefore, weight management in overweight women and men. Further studies are required to determine whether higher doses of β -glucan affect short-term satiety and energy intake when the sample size is larger.

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References

1. Almiron-Roig, E., Flores, S. Y., and Drewnowski, A. No difference in satiety or in subsequent energy intakes between a beverage and a solid food. *Physiol. Behav.* 82: 671, 2004.
2. Battilana, P., Ornstein, K., Minehira, K., Schwarz, J. M., Acheson, K., Schneiter, P., Burri, J., Jequier, E., and Tappy, L. Mechanisms of action of beta-glucan in postprandial glucose metabolism in healthy men. *Eur. J. Clin. Nutr.* 55:327, 2001.
3. Behall, K. M., Scholfield, D. J., and Hallfrisch, J. Comparison of hormone and glucose responses of overweight women to barley and oats. *J. Am. Coll. Nutr.* 24:182, 2005.
4. Bourdon, I., Yokoyama, W., Davis, P., Hudson, C., Backus, R., Richter, D., Knuckles, B., and Schneeman, B. O. Postprandial lipid, glucose, insulin, and cholecystokinin responses in men fed barley pasta enriched with beta-glucan. *Am. J. Clin. Nutr.* 69:55, 1999.
5. Braaten, J. T., Scott, F. W., Wood, P. J., Riedel, K. D., Wolynetz, M. S., Brule, D., and Collins, M. W. High beta-glucan oat bran and oat gum reduce postprandial blood glucose and insulin in subjects with and without type 2 diabetes. *Diabetes Med.* 11:312, 1994.
6. Burley, V. J., Paul, A. W., and Blundell, J. E. Sustained post-ingestive action of dietary fibre effects of sugar beet fibre supplements on satiety. *J. Hum. Nutr. Diet* 6:43, 1993.
7. Cardello, A. V., Schutz, H. G., Leshner, L. L., and Merrill, E. Development and testing of a labeled magnitude scale of perceived satiety. *Appetite* 44:1, 2005.
8. Evans, R. G. Clinical relevance of the Marlowe-Crowne Scale: A review and recommendations. *J. Pers. Assess.* 46:415, 1982.
9. Hallfrisch, J., Scholfield, D. J., and Behall, K. M. Physiological responses of men and women to barley and oat extracts (Nu-trimX). II. Comparison of glucose and insulin responses. *Cereal Chem.* 80:80, 2003.
10. Hulshof, T., De Graaf, C., and Weststrate, J. A. The effects of preloads varying in physical state and fat content on satiety and energy intake. *Appetite* 21:273, 1993.
11. Jacob, D. Physician-assisted suicide: MNA involvement in the debate. *Mich. Nurse* 66: 5, 1993.
12. Jenkins, A. L., Jenkins, D. J., Zdravkovic, U., Wursch, P., and Vuksan, V. Depression of the glycemic index by high levels of beta-glucan fiber in two functional foods tested in type 2 diabetes. *Eur. J. Clin. Nutr.* 56: 622, 2002.
13. Kabir, M., Oppert, J. M., Vidal, H., Bruzzo, F., Fiquet, C., Wursch, P., Slama, G., and Rizkalla, S. W. Four-week low-glycemic index breakfast with a modest amount of soluble fibers in type 2 diabetic men. *Metabolism* 51:819, 2002.
14. Kaplan, R. J., and Greenwood, C. E. Influence of dietary carbohydrates and glycaemic response on subjective appetite and food intake in healthy elderly persons. *Int. J. Food. Sci. Nutr.* 53:305, 2002.
15. Kovacs, E. M., Westerterp-Plantenga, M. S., Saris, W. H., Goossens, I., Geurten, P., and Brouns, F. The effect of addition of modified guar gum to a low-energy semisolid meal on appetite and body weight loss. *Int. J. Obes. Relat. Metab. Disord.* 25:307, 2001.
16. Krotkiewski, M. Effect of guar gum on body-weight, hunger ratings and metabolism in obese subjects. *Br. J. Nutr.* 52:97, 1984.
17. Leeds, A. R. Dietary fibre: Mechanisms of action. *Int. J. Obes.* 11(Suppl. 1):3, 1987.
18. Liljeberg, H. G., Granfeldt, Y. E., and Björck, I. M. Products based on a high fiber barley genotype, but not on common barley or oats, lower postprandial glucose and insulin responses in healthy humans. *J. Nutr.* 126:458, 1996.
19. Ludwig, D. S., Majzoub, J. A., Al-Zahrani, A., Dallal, G. E., Blanco, I., and Roberts, S. B. High glycemic index foods, overeating, and obesity. *Pediatrics* 103:E26, 1999.
20. Ludwig, D. S., Peterson, K. E., and Gortmaker, S. L. Relation between consumption of sugar-sweetened drinks and childhood obesity: A prospective, observational analysis. *Lancet* 357:505, 2001.
21. McCleary, B. V., and Glennie-Holmes, M. Enzymatic quantification of (1-3), (1-4)- β -D-glucan in barley and malt. *J. Inst. Brew.* 91:285, 1985.
22. Mickelsen, O., Makdani, D. D., Cotton, R. H., Titcomb, S. T., Colmery, J. C., and Gatty, R. Effects of a high fiber bread diet on weight loss in college-age males. *Am. J. Clin. Nutr.* 32:1703, 1979.
23. Pasman, W. J., Saris, W. H., Wauters, M. A., and Westerterp-Plantenga, M. S. Effect of one week of fibre supplementation on hunger and satiety ratings and energy intake. *Appetite* 29:77, 1997.
24. Pereira, M. A., and Ludwig, D. S. Dietary fiber and body-weight regulation: Observations and mechanisms. *Pediatr. Clin. N. Am.* 48:969, 2001.
25. Rytter, E., Erlanson-Albertsson, C., Lindahl, L., Lundquist, I., Viberg, U., Akesson, B., and Oste, R. Changes in plasma insulin, enterostatin, and lipoprotein levels during an energy-restricted dietary regimen including a new oat-based liquid food. *Ann. Nutr. Metab.* 40:212, 1996.
26. Saltzman, E., Moriguti, J. C., Das, S. K., Corrales, A., Fuss, P., Greenberg, A. S., and Roberts, S. B. Effects of a cereal rich in soluble fiber on body composition and dietary compliance during consumption of a hypocaloric diet. *J. Am. Coll. Nutr.* 20:50, 2001.
27. Stunkard, A. J., and Messick, S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J. Psychosom. Res.* 29:71, 1985.
28. Tappy, L., Gugolz, E., and Wursch, P. Effects of breakfast cereals containing various amounts of beta-glucan fibers on plasma glucose and insulin responses in NIDDM subjects. *Diabetes Care* 19:831, 1996.
29. Tiwary, C. M., Ward, J. A., and Jackson, B. A. Effect of pectin on satiety in healthy US Army adults. *J. Am. Coll. Nutr.* 16:423, 1997.
30. Tournier, A., and Louis-Sylvestre, J. Effect of the physical state of a food on subsequent intake in human subjects. *Appetite* 16:17, 1991.
31. Wolever, T. M., and Bolognesi, C. Source and amount of carbohydrate affect postprandial glucose and insulin in normal subjects. *J. Nutr.* 126:2798, 1996.
32. Wood, P. J., Beer, M. U., and Butler, G. Evaluation of role of concentration and molecular weight of oat beta-glucan in determining effect of viscosity on plasma glucose and insulin following an oral glucose load. *Br. J. Nutr.* 84:19, 2000.
33. Xiong, Y., Miyamoto, N., Shibata, K., Valasek, M. A., Motoike, T., Kedzierski, R. M., and Yanagisawa, M. Short-chain fatty acids stimulate leptin production in adipocytes through the G protein-coupled receptor GPR41. *Proc. Natl. Acad. Sci. USA* 101:1045, 2004.
34. Yokoyama, W. H., Hudson, C. A., Knuckles, B. E., Chiu, M. C., Sayre, R. N., Turnlund, J. R., and Schneeman, B. O. Effect of barley β -glucan in durum wheat pasta on human glycemic response. *Cereal Chem.* 74: 293, 1997.